

ATS612LSB

DYNAMIC, SELF-CALIBRATING, PEAK-DETECTING, DIFFERENTIAL HALL-EFFECT GEAR-TOOTH SENSOR

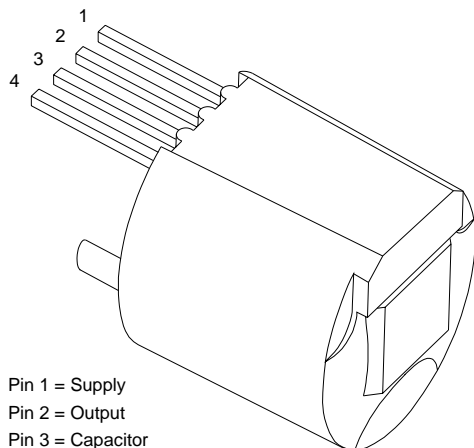
The ATS612LSB gear-tooth sensor is a peak detecting device that uses automatic gain control to provide extremely accurate gear edge detection down to low operating speeds. Each sensor module consists of a high-temperature plastic shell that holds together a samarium-cobalt magnet, a pole piece, and a differential open-collector Hall IC that has been optimized to the magnetic circuit. This small package can be easily assembled and used in conjunction with a wide variety of gear shapes and sizes.

The gear-sensing technology used for this sensor is Hall-effect based. The sensor incorporates a dual-element Hall IC that switches in response to differential magnetic signals created by ferrous targets. The sophisticated processing circuitry contains a 5-bit A/D converter that self-calibrates (normalizes) the internal gain of the device to minimize the effect of air-gap variations. The patented peak-detecting filter circuit eliminates magnet and system offsets and has the ability to discriminate relatively fast changes such as those caused by tilt, gear wobble, and eccentricities yet provides stable operation to extremely low RPM.

These sensor systems are ideal for use in gathering speed, position, and timing information using gear-tooth-based configurations. The ATS612LSB is particularly suited to those applications that require extremely accurate duty cycle control or accurate edge detection such as in automotive crank shaft applications. The lower vibration sensitivity also makes this device extremely useful for transmission speed sensing.

ATS612LSB: Large/small-tooth gear-position sensing — crank angle, transmission speed, cam angle.

continued next page...



Dwg. AH-006

ABSOLUTE MAXIMUM RATINGS over operating temperature range

Supply Voltage, V_{CC}	24 V*
Reverse Supply Voltage, V_{RCC}	-16 V
Output OFF Voltage, V_{OUT}	24 V
Continuous Output Current, I_{OUT}	25 mA†
Reverse Output Current, I_{ROUT}	50 mA
Package Power Dissipation, P_D	See Graph
Operating Temperature Range, T_A	-40°C to +150°C*
Storage Temperature, T_S	+170°C

* Operation at increased supply voltages with external circuitry is described in Applications Information. Devices for operation at increased temperatures are available on special order.

† Output is current limited at 25 mA to 55 mA. Continued operation in this mode can cause excessive device heating and failure. See graph, next page.

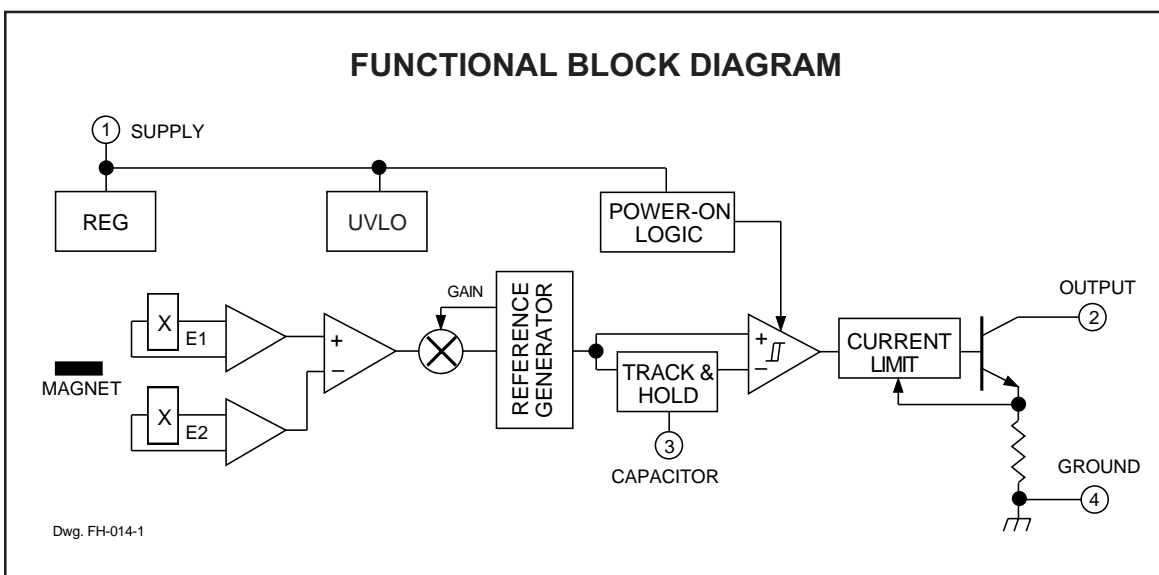
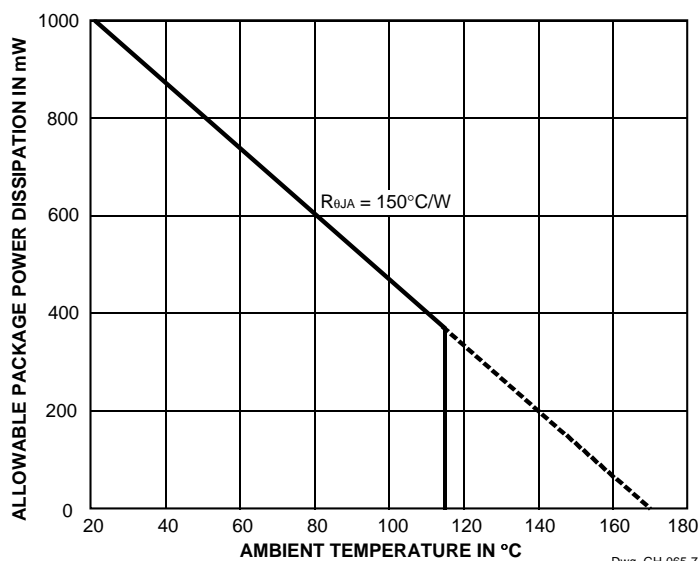
Always order by complete part number: **ATS612LSB**.

ATS612LSB

DYNAMIC, SELF-CALIBRATING, PEAK-DETECTING, DIFFERENTIAL HALL-EFFECT GEAR-TOOTH SENSOR

FEATURES AND BENEFITS

- Fully Optimized Differential Digital Gear-Tooth Sensor
- Single-Chip Sensing IC for High Reliability
- Digital Output Representing Target Profile
- Extremely Low Timing Accuracy Drift with Temperature
- Large Operating Air Gaps
- Small Mechanical Size
- Optimized Magnetic Circuit
- Patented Peak-Detecting Filter:
80 μ s Typical Power-On Time
<10 RPM Operation (single-tooth target)
Correct First-Edge Detection
Uses Small Value Ceramic Capacitors
- Under-Voltage Lockout
- Wide Operating Voltage Range
- Defined Power-On State



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ELECTRICAL CHARACTERISTICS over operating voltage and temperature range,
 $C_3 = 0.1 \mu\text{F}$ to $0.47 \mu\text{F}$.

Characteristic	Symbol	Test Conditions	Limits			
			Min.	Typ.	Max.	Units
Supply Voltage	V_{CC}	Operating, $T_J < 165^\circ\text{C}$	3.6	–	24	V
Power-On State	POS	$V_{CC} = 0 \rightarrow 5 \text{ V}$	HIGH	HIGH	HIGH	–
Under-Voltage Lockout	$V_{CC(UV)}$	$V_{CC} = 0 \rightarrow 5 \text{ V}$	2.5	–	3.6	V
Under-Voltage Hysteresis	$V_{CC(hys)}$	$V_{CC(UV)} - V_{CC(SD)}$	–	0.2	–	V
Low Output Voltage	$V_{OUT(SAT)}$	$I_{OUT} = 20 \text{ mA}$	–	190	400	mV
Output Current Limit	I_{OUTM}	$V_{OUT} = 12 \text{ V}$	25	45	55	mA
Output Leakage Current	I_{OFF}	$V_{OUT} = 24 \text{ V}$	–	0.2	15	μA
Supply Current	I_{CC}	Output OFF	6.0	8.2	13	mA
		Output ON	8.0	10	15	mA
Power-On Delay	t_{on}	$V_{CC} > 5 \text{ V}$	–	80	500	μs
Output Rise Time	t_r	$R_L = 500 \Omega$, $C_L = 10 \text{ pF}$	–	0.2	5.0	μs
Output Fall Time	t_f	$R_L = 500 \Omega$, $C_L = 10 \text{ pF}$	–	0.2	5.0	μs

NOTES: Typical data is at $V_{CC} = 8 \text{ V}$ and $T_A = +25^\circ\text{C}$ and is for design information only.

$V_{CC(SD)}$ = shutdown voltage, $V_{CC} = 5 \text{ V} \rightarrow 0$.

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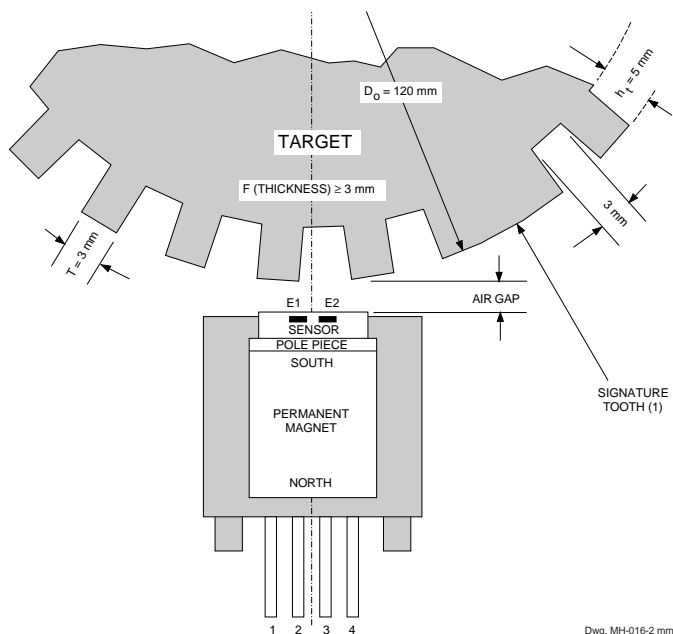
DYNAMIC, SELF-CALIBRATING, PEAK-DETECTING, DIFFERENTIAL HALL-EFFECT GEAR-TOOTH SENSOR

OPERATION over operating voltage and temperature range with reference target
(unless otherwise specified).

Characteristic	Symbol	Test Conditions	Limits			
			Min.	Typ.	Max.	Units
Air Gap Range	AG	Operating, Target Speed > 20 RPM	0.4	–	2.5	mm
Calibration Cycle	n_{cal}	Output edges before which calibration is completed*	1	1	1	Edge
Calibration Mode Disable	n_{dis}	Output falling edges for startup calibration to be complete	64	64	64	Edges
Timing Accuracy	t_{θ}	Target Speed = 1000 RPM, $0.4 \text{ mm} \leq AG \leq 2 \text{ mm}$	–	± 0.5	± 0.75	$^{\circ}$

* Non-uniform magnetic profiles may require additional output pulses before calibration is completed.

REFERENCE TARGET

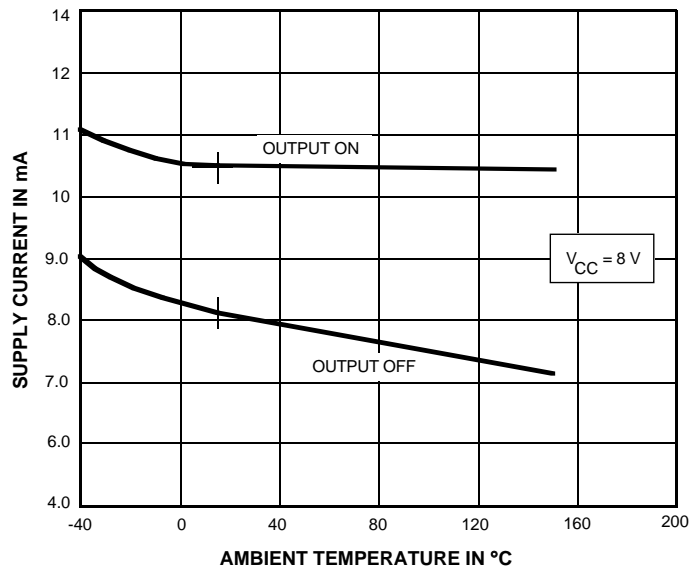


Dwg. MH-016-2 mm

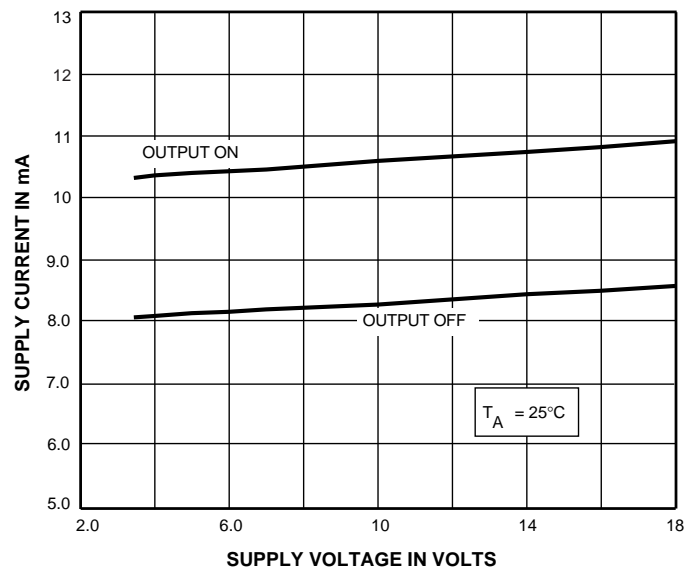
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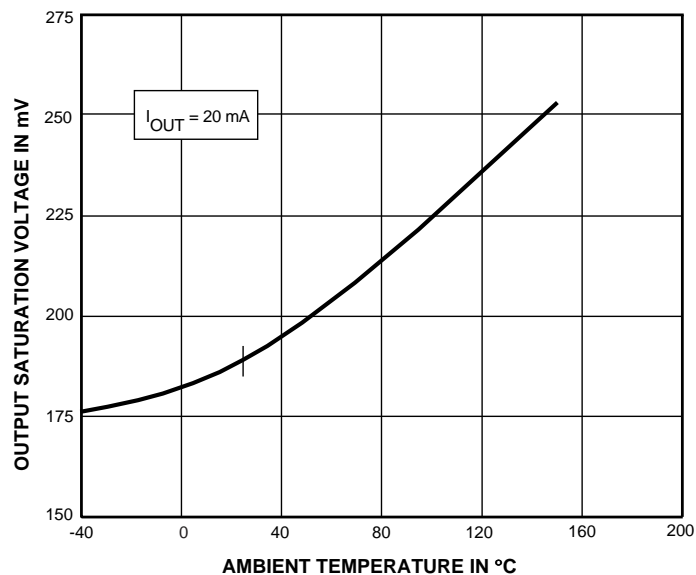
TYPICAL ELECTRICAL CHARACTERISTICS



Dwg. GH-014-2



Dwg. GH-058-1

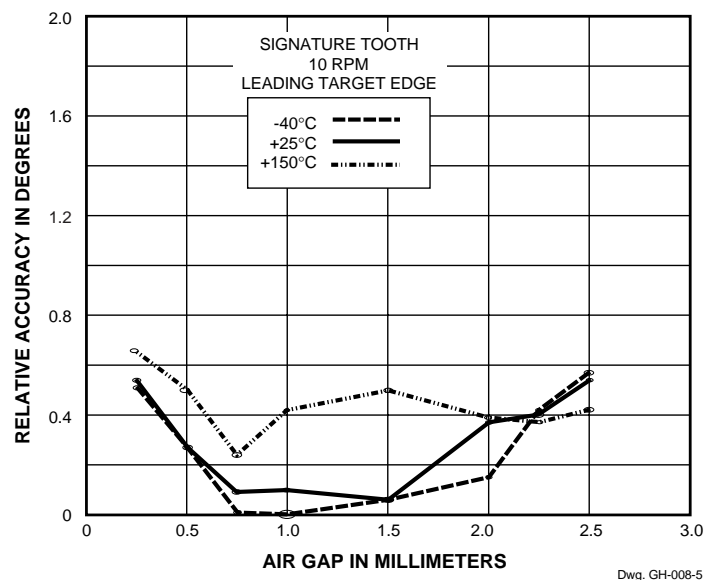
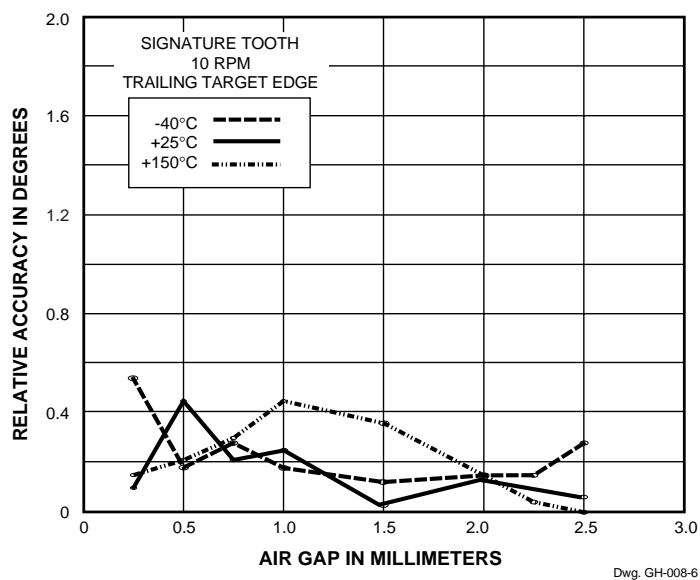
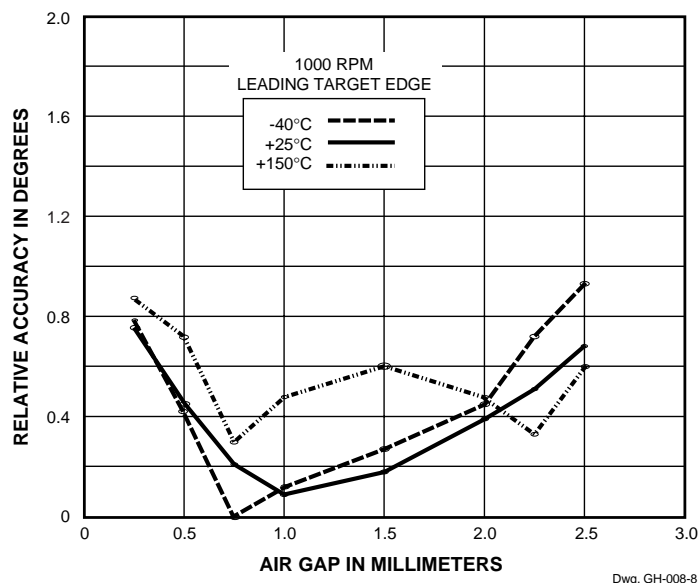
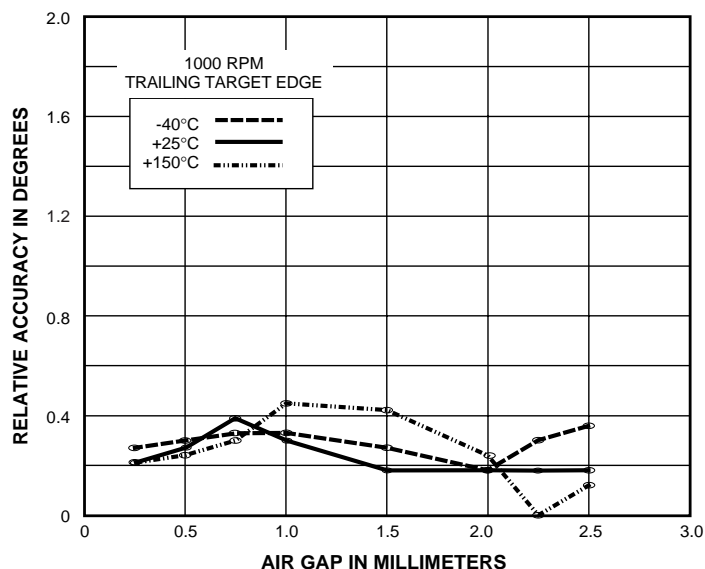


Dwg. GH-013-2

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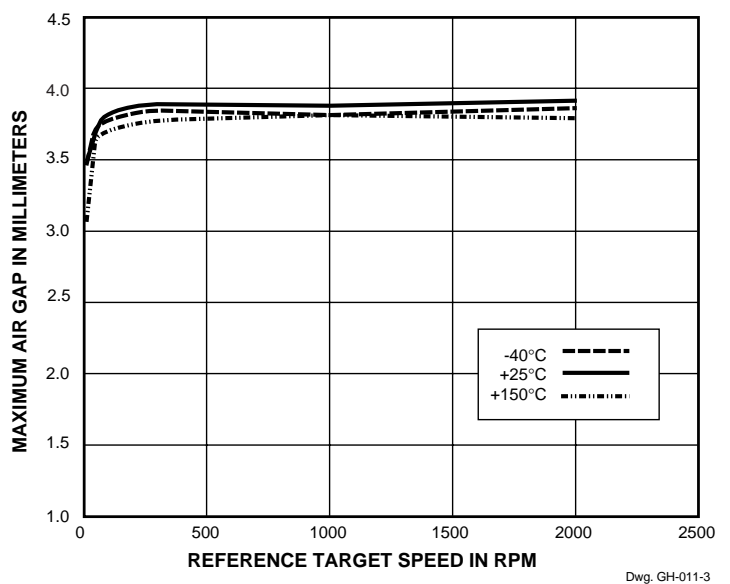
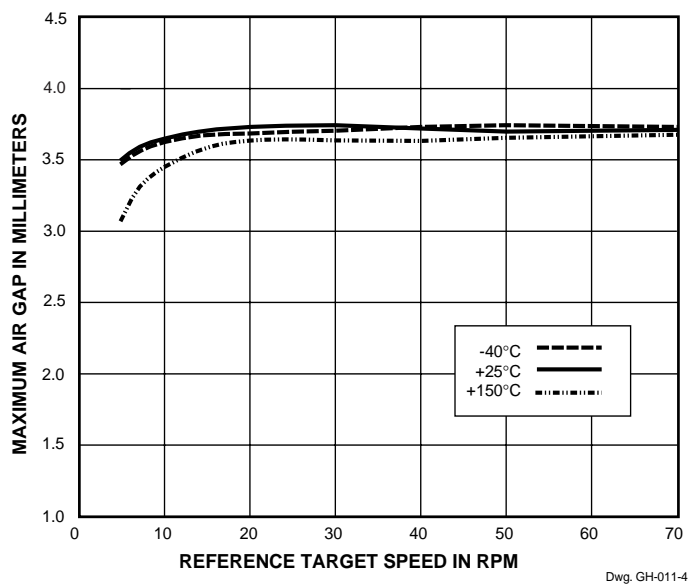
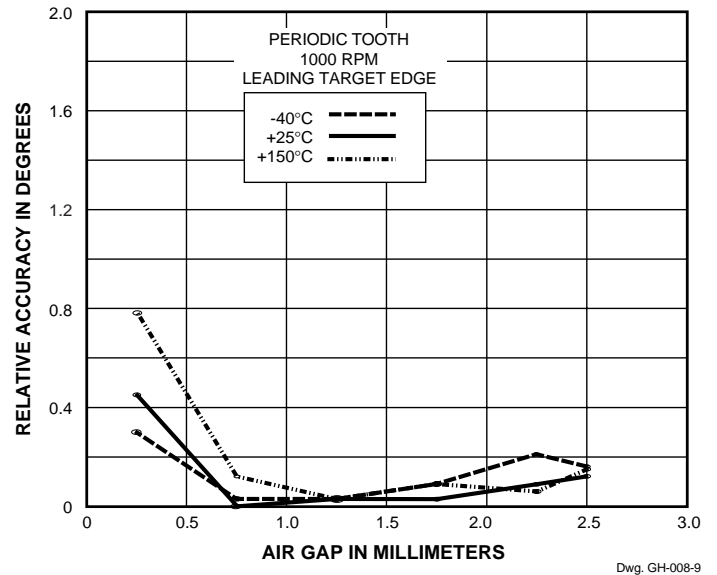
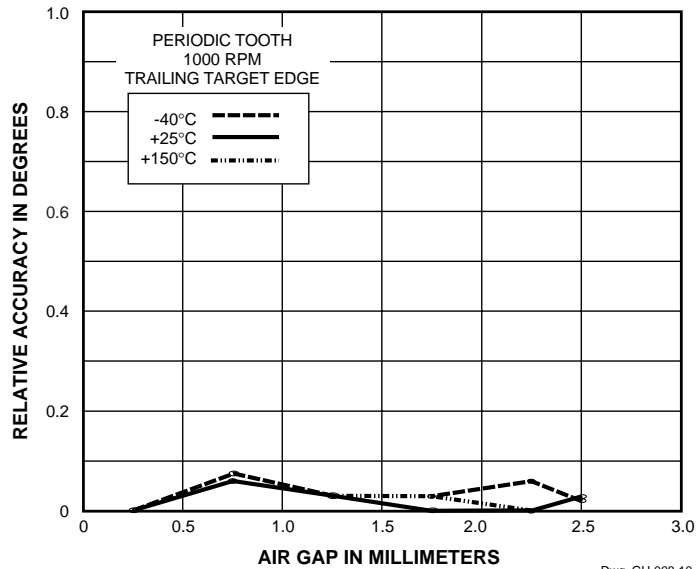
TYPICAL OPERATING CHARACTERISTICS (with reference target)



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TYPICAL OPERATING CHARACTERISTICS (with reference target) — Continued



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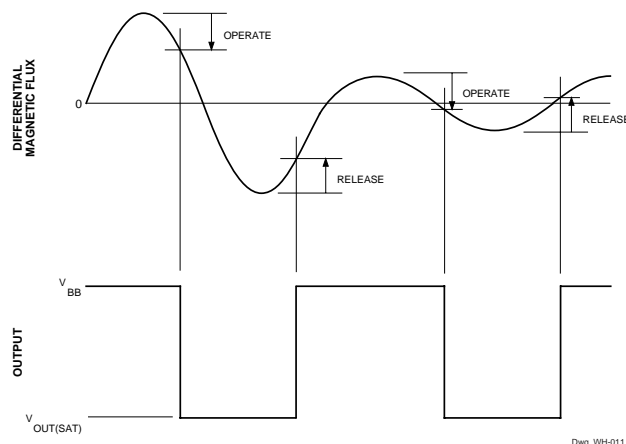
DEVICE DESCRIPTION

The ATS612LSB gear-tooth sensor system is a Hall IC/magnet configuration that is fully optimized to provide digital detection of gear-tooth edges in a small package size. This device contains self-calibrating circuitry that nulls out the effect of air gap variations on the switching accuracy of the device. A high startup hysteresis minimizes false switching caused by magnetic overshoot. The sensor is packaged in a miniature plastic housing that has been optimized for size, ease of assembly, and manufacturability. High operating temperature materials are used in all aspects of construction.

The use of this sensor is simple; after correct power is applied to the component, it is capable of instantly providing digital information that is representative of the profile of a rotating gear. No additional optimization or processing circuitry is required. This ease of use should reduce design time and incremental assembly costs for most applications.

Sensing Technology. This gear-tooth sensor module contains a single-chip differential Hall-effect sensor IC, a samarium-cobalt magnet, and a flat ferrous pole piece. The Hall IC consists of two Hall elements located so as to measure the magnetic gradient created by the passing of a ferrous object (a gear). The two elements measure the field gradient and convert it to voltage which is then subtracted and processed in order to provide a digital output signal.

The processing circuit uses a patented peak detection scheme to eliminate magnet and system offsets. This technique allows dynamic coupling and filtering of offsets without the power-up and settling time disadvantages of classical high-pass filtering schemes. The peak signal of every tooth and valley is detected by the filter and is used to provide an instant reference for the operate and release point comparator. In this manner, the thresholds are adapted and referenced to individual signal peaks and valleys, hence providing immunity to zero line variation due to installation inaccuracies (tilt, rotation, and off center placement), as well as for variations caused by target and shaft eccentricities. The peak detection concept also allows extremely low speed operation for small value filter capacitors.



The ATS612LSB also includes self-calibration circuitry that is engaged at power on. The signal amplitude is measured and the device gain is normalized. In this manner, switch-point drift versus air gap is minimized and excellent timing accuracy can be achieved. The AGC circuitry, in conjunction with a unique hysteresis circuit, also eliminates the effect of gear edge overshoot as well as increases the immunity to false switching caused by gear tooth anomalies at close air gap. The AGC circuit sets the gain of the device after power on. Up to 0.25 mm air gap change can occur after calibration is complete without significant performance impact.

Superior Performance. The ATS612LSB peak-detecting differential gear-tooth sensor module has several advantages over conventional Hall-effect gear-tooth sensors. The signal-processing techniques used in the ATS612LSB peak-detecting differential gear-tooth sensor solve the catastrophic issues that affect the functionality of conventional digital gear-tooth sensors.

- **Temperature drift.** Changes in temperature do not greatly affect this device due to the stable amplifier design and the offset rejection circuitry.
- **Timing accuracy variation due to air gap.** The accuracy variation caused by air gap changes is minimized by the self calibration circuitry. A 2x-to-3x improvement can be seen.
- **Dual edge detection.** Because this device switches from the positive and negative peaks of the signal, dual edge detection is guaranteed.

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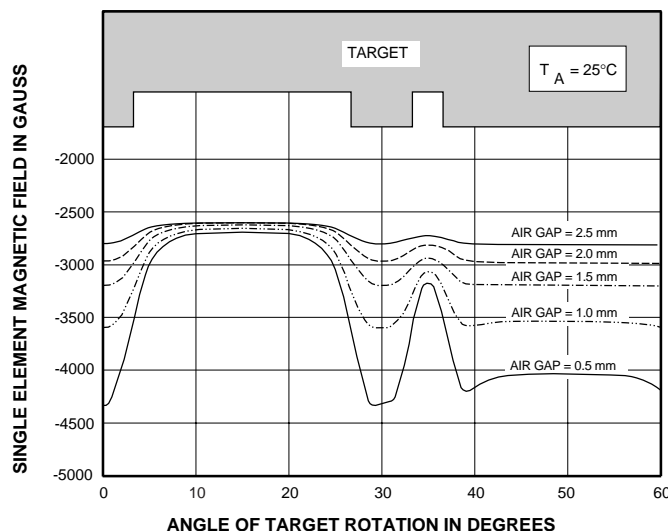
DYNAMIC, SELF-CALIBRATING, PEAK-DETECTING, DIFFERENTIAL HALL-EFFECT GEAR-TOOTH SENSOR

DEVICE DESCRIPTION — Continued

- **Tilted or off-center installation.** Traditional differential sensors will switch incorrectly due to baseline changes versus air gap caused by tilted or off center installation. The peak detector circuitry references the switch point from the peak and is immune to this failure mode. There may be a timing accuracy shift caused by this condition.
- **Large operating air gaps.** Operating air gaps greater than 2.5 mm are easily achievable (dependent on target dimensions, material, and speed) with this device due to the sensitive switch points after start up.
- **Immunity to magnetic overshoot.** The air gap-independent hysteresis minimizes the impact of overshoot on the switching of device output.
- **Response to surface defects in the target.** The gain-adjust circuitry reduces the effect of minor gear anomalies that would normally cause false switching.
- **Immunity to vibration and backlash.** The gain-adjust circuitry keeps the hysteresis of the device roughly proportional to the peak to peak signal. This allows the device to have good immunity to vibration even when operating at close air gaps.
- **Immunity to gear run out.** The differential sensor configuration eliminates the base line variations caused by gear run out.

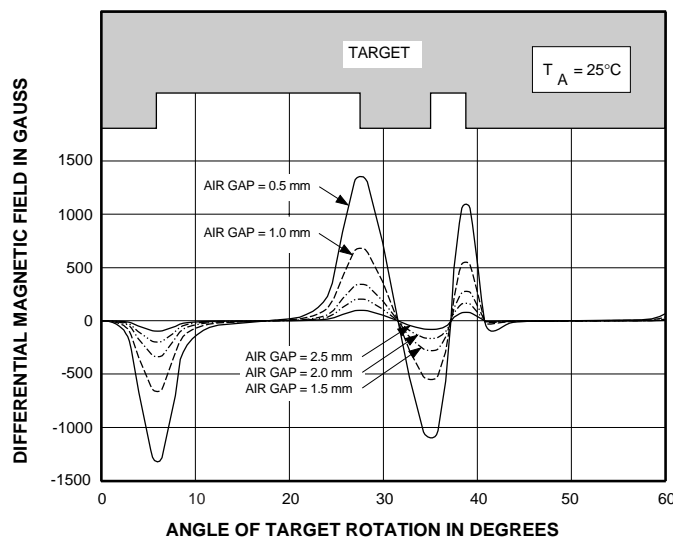
Differential vs. Single-Element Sensing. The differential Hall-element configuration is superior in most applications to the classical single-element gear-tooth sensor. As shown in the flux maps on this page, the single-element configuration commonly used (Hall-effect sensor mounted on the face of a simple permanent magnet) requires the detection of a small signal (often <100G) that is superimposed on a large back-biased field, often 1500G to 3500G. For most gear/target configurations, the back-biased field values change due to concentration effects, resulting in a varying baseline with air gap, with valley widths, with eccentricities, and with vibration. The differential configuration cancels the effects of the back-biased field and avoids many of the issues presented by the single Hall element.

NOTE — 10 G = 1 mT, exactly.



Dwg. GH-061-1

**Single-element flux maps
showing the impact of varying valley widths**



Dwg. GH-061

Differential flux maps vs. air gaps

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DEVICE DESCRIPTION — Continued

Peak-Detecting vs. AC-Coupled Filters. High-pass filtering (normal ac coupling) is a commonly used technique for eliminating circuit offsets. AC coupling has errors at power on because the filter circuit needs to hold the circuit zero value even though the circuit may power on over a large signal. Such filter techniques can only perform properly after the filter has been allowed to settle, which is typically greater than one second. Also, high-pass filter solutions cannot easily track rapidly changing baselines such as those caused by eccentricities. Peak detection switches on the change in slope of the signal and is baseline independent at power up and during running.

Peak Detecting vs. Zero-Crossing Reference. The usual differential zero-crossing sensors are susceptible to false switching due to off-center and tilted installations, which result in a shift in baseline that changes with air gap. The track-and-hold peak-detection technique ignores baseline shifts versus air gaps and provides increased immunity to false switching. In addition, using track-and-hold peak-detecting techniques, increased air gap capabilities can be expected because a peak detector utilizes the entire peak-to-peak signal range as compared

to zero-crossing detectors that switch on one-half the peak-to-peak signal.

NOTE — “Baseline” refers to the zero-gauss differential where each Hall-effect element is subject to the same magnetic field strength.

Power-On Operation. The device will power on in the OFF state (output high) irrespective of the magnetic field condition. The power-up time of the circuit is no greater than 500 μ s. The circuit is then ready to accurately detect the first target edge that results in a HIGH-to-LOW transition.

Under-Voltage Lockout. When the supply voltage is below the minimum operating voltage ($V_{CC(UV)}$), the device is OFF and stays OFF irrespective of the state of the magnetic field. This prevents false signals, which may be caused by under-voltage conditions (especially during turn on), from appearing at the output.

Output. The device output is an open-collector stage capable of sinking up to 20mA. An external pull-up (resistor) to a supply voltage of not more than 24V must be supplied.

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CRITERIA FOR DEVICE QUALIFICATION

All Allegro sensors are subjected to stringent qualification requirements prior to being released to production. To become qualified, except for the destructive ESD tests, no failures are permitted.

Qualification Test	Test Method and Test Conditions	Test Length	Samples Per Lot	Comments
Temperature Humidity Bias Life	JESD22-A101, $T_A = 85^{\circ}\text{C}$, RH = 85%	1000 hrs	77	Device biased for minimum power
Bias Life	JESD22-A108, $T_A = 150^{\circ}\text{C}$, $T_J = 165^{\circ}\text{C}$	1000 hrs	77	
(Surge Operating Life)	JESD22-A108, $T_A = 175^{\circ}\text{C}$, $T_J = 190^{\circ}\text{C}$	168 hrs	77	
Autoclave, Unbiased	JESD22-A102, $T_A = 121^{\circ}\text{C}$, 15 psig	96 hrs	77	
High-Temperature (Bake) Storage Life	JESD22-A103, $T_A = 170^{\circ}\text{C}$	1000 hrs	77	
Temperature Cycle	JESD22-A104	1000 cycles	77	-55°C to $+150^{\circ}\text{C}$
ESD, Human Body Model	CDF-AEC-Q100-002	Pre/Post Reading	3 per test	Test to failure Pin 3 > 1.5 kV All other pins > 3 kV

GEAR/TARGET SYSTEM EVALUATION*

An analog map of the magnetic signal can be obtained by measuring the voltage at pin 3 (the capacitor pin) while the device is running. The peak and valley hold voltage will represent the peak-to-peak value of the signal. More accurate measurements can be taken by connecting an extremely small capacitor ($0.05\ \mu\text{F}$) from pin 3 to ground. After the device is powered up and has switched at least 64 times, a $1\ \text{k}\Omega$ bleed-off resistor should be installed in parallel with the capacitor without powering down the device. If the gear is then rotated at an extremely low speed, an analog representation of the gain-

adjusted signal can be measured at pin 3. Note that the device should be re-powered at each air gap and the above procedure repeated for accurate measurements. In both cases, the analog signal may be compared to the typical hysteresis of the device and device performance can be estimated.

* In application, the terms "gear" and "target" are often interchanged. However, "gear" is preferred when motion is transferred.

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APPLICATIONS INFORMATION

Recommended Evaluation Technique. The self-calibrating feature of the ATS612LSB requires that a special evaluation technique be used to measure its high-accuracy performance capabilities. Installation inaccuracies are calibrated out at power on only; hence, it is extremely important that the device be re-powered at each air gap when gathering timing accuracy data.

Self-Calibrating Functions. The ATS612LSB is designed to minimize performance variation caused by the large air gap variations resulting from installation by self-calibrating at power-on. This function should be tested using the following procedure.

1. Set the air gap to the desired value.
2. Power down and then power on the device.
3. Rotate the target at the desired speed.
4. Wait for calibration to complete (64 output pulses to occur).
5. Monitor output for correct switching and measure accuracy.
6. Repeat the above for multiple air gaps within the operating range of the device.
7. This can be repeated over the entire operating temperature range.

Measurement of the effect of changing air gap after power on:

1. Set the air gap to the desired value (nominal, for example). Rotate the target at the desired speed. Apply power to the module. Wait for 64 output pulses to occur. Monitor output for correct switching and measure accuracy.
2. Change the air gap by ± 0.25 mm. Do not re-power module. Monitor the output for correct switching and measure accuracy.

Gear Diameter and Pitch. Signal frequency is a direct function of gear pitch and rotational speed (RPM). The width of the magnetic signal in degrees and, hence, the signal slope created by the tooth is directly proportional to the circumference of the gear (πD_O). Smaller diameters limit the low-speed operation due to the slower rate of change of the magnetic signal per degree of gear rotation (here the limitation is the droop of the capacitor versus the signal change). Larger diameters limit high-speed operation due to the higher rate of change of magnetic signal per degree of rotation (here the limitation is the maximum charge rate of the capacitor versus the rate of signal change). These devices are optimized for a 50mm gear diameter (signal not limited by tooth width), 0.22 μ F capacitor, and speeds of 10 RPM to 8000 RPM. For very large diameter gears (diameter >200 mm), the devices must be configured with a lower value capacitor, but not less than 0.1 μ F. This allows for a range of 5:1 in gear diameters.

Air Gap and Tooth Geometry. Operating specifications are impacted by tooth width (T), valley width ($p_c - T$) and depth (h_t), gear material, and gear face thickness (F). The target can be a gear or a specially cut shaft-mounted tone wheel made of stamped ferrous metal. In general, the following gear or target guidelines must be followed to achieve greater than 2mm air gap from the face of unit:

Tooth width, T	>2 mm
Valley width, $p_c - T$	>2 mm
(Whole) depth, h_t	>3 mm
Gear material	low-carbon steel
Gear face width (thickness), F	>3 mm

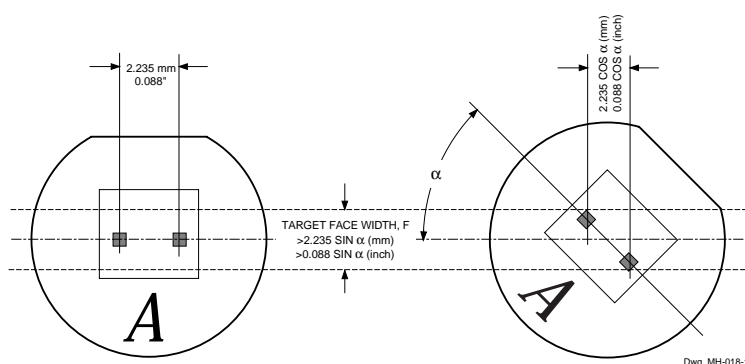
Deviation from these guidelines will result in a reduction of air gap and a deterioration in timing accuracy.

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APPLICATIONS INFORMATION — Continued

Operation with Fine-Pitch gears. For targets with a circular pitch of less than 4mm, a performance improvement can be observed by rotating the front face of the sensor. This sensor rotation decreases the effective sensor-to-sensor spacing and increases the capability of detecting fine tooth or valley configurations, provided that the Hall elements are not rotated beyond the width of the target.

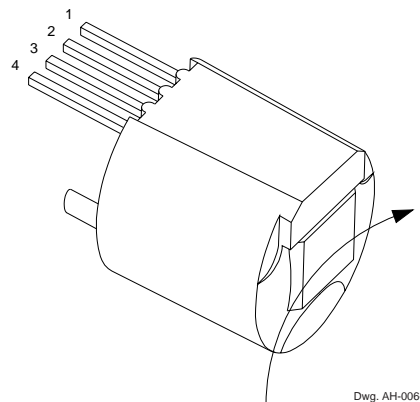


Signal Timing Accuracy. The magnetic field profile width is defined by the sensor element spacing and narrows in degrees as the target diameter increases. This results in improved timing accuracy performance for larger gear diameters (for the same number of gear teeth). Valley-to-tooth transitions will generally provide better accuracy than tooth-to-valley transitions for large-tooth or large-valley configurations. For highest accuracy, targets greater than 100mm in diameter should be used.

Signal Duty Cycle. For repetitive target structures, precise duty cycle is maintained over the operating air gap and temperature range due to an extremely good symmetry in the magnetic switch points and the internal self calibration of the device. For irregular tooth geometries, there will be a small but measureable change in pulse width versus air gap.

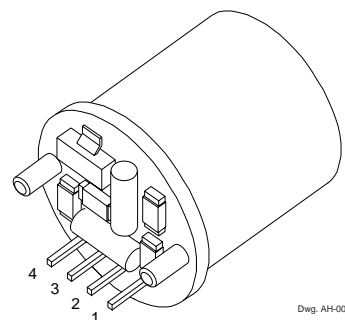
Output Polarity. The output of the device will switch from HIGH to LOW as the leading edge of the target passes the module in the direction indicated below (pin 4 to pin 1), which means that the output will be LOW when the unit is facing a tooth. If rotation is in the opposite direction (pin 1

to pin 4), the output of the device will switch from LOW to HIGH as the leading edge of the target passes the module, which means that the output will be HIGH when the unit is facing a tooth.



Power Supply Protection. The sensor contains an on-chip voltage regulator and can operate over a wide supply voltage range. For devices that need to operate from an unregulated power supply, transient protection should be added externally. For applications using a regulated supply, external EMI/RFI protection is often required. Insufficient protection can result in unexplained pulses on the output line, providing inaccurate sensing information to the user.

The filter capacitor and EMI protection circuitry can easily be added to a PC board for use with these devices. Provisions have been made for simple mounting of a board on the back of the unit.

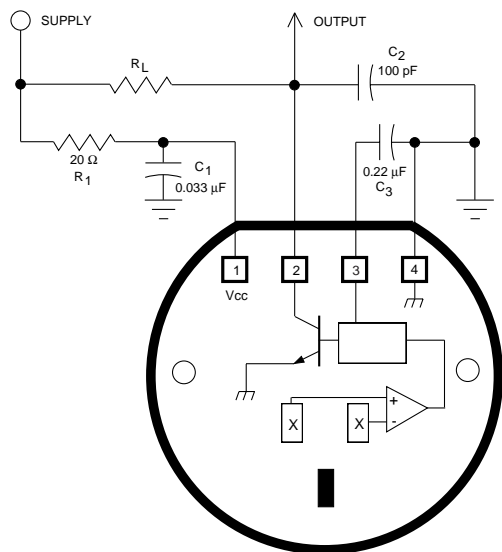


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APPLICATIONS INFORMATION — Continued

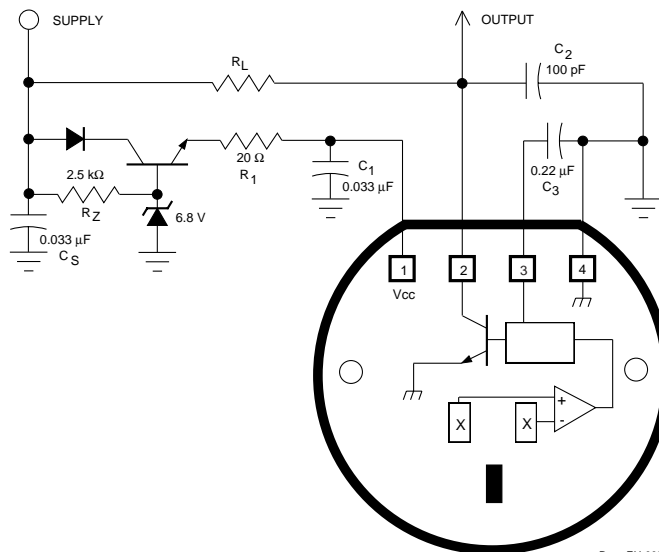
Operation From a Regulated Power Supply. These devices require minimal protection circuitry during operation from a low-voltage regulated line. The on-chip voltage regulator provides immunity to power supply variations between 3.6V and 24V. However, even while operating from a regulated line, some supply and output filtering is required to provide immunity to coupled and injected noise on the supply line. A basic RC low-pass circuit (R_1C_1) on the supply line and an optional output capacitor (C_2) is recommended for operation in noisy environments. Because the device has an open-collector output, an output pull-up resistor (R_L) must be included either at the sensor output (pin 2) or by the signal processor input.



Dwg. EH-008-1A

Operation From an Unregulated Power Supply. In automotive applications, where the device receives its power from an unregulated supply such as the battery, full protection is generally required so that the device can withstand the many supply-side transients. Specifications for such transients vary between car manufacturers, and protection-circuit design should be optimized for each application. In the circuit below, a simple Zener-controlled regulator is constructed using discrete components. The RC low-pass filter on the supply line (R_1C_1) and a low-value supply bypass capacitor (C_S) can be included, if necessary, so as to minimize susceptibility to EMI/RFI. The npn transistor should be chosen with sufficiently high forward breakdown voltage so as to withstand supply-side transients. The series diode should be chosen with

sufficiently high reverse breakdown capabilities so as to withstand the most negative transient. The current-limiting resistor (R_Z) and the Zener diode should be sized for power dissipation requirements.



Dwg. EH-008A

Capacitor Requirements. The choice of the capacitor at pin 3 (C_3) defines the minimum operating speed of the target. This capacitor (0.1 μ F minimum) is required to stabilize the internal amplifiers as well as to eliminate the signal offsets. Typically, a 0.22 μ F low-leakage ceramic capacitor is recommended. Values greater than 0.47 μ F should not be used as this may cause high-speed performance degradation.

Capacitor leakage current at pin 3 will cause degradation in the low-speed performance of the device. Excess capacitor leakage can result in the sensor changing output state without movement of the gear tooth being sensed. In addition to the capacitor leakage, it is extremely important to minimize the leakage at the PC board and between the pins of the sensor. Up to 50nA of external leakage can be tolerated at the capacitor pin node to ground. Choice of low-leakage-current potting compounds and the use of clean PC board techniques are extremely important.

Additional applications information on gear-tooth and other Hall-effect sensors is provided in the *Allegro Integrated and Discrete Semiconductors Data Book* or *Application Note 27701*.

ATS612LSB

DYNAMIC, SELF-CALIBRATING, PEAK-DETECTING, DIFFERENTIAL HALL-EFFECT GEAR-TOOTH SENSOR

MECHANICAL INFORMATION

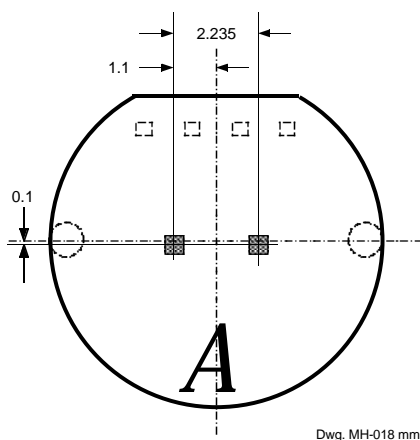
Component	Material	Function	Units
Sensor Face	Thermoset epoxy	Maximum temperature	170°C*
Plastic Housing	Thermoplastic PBT, 30% glass filled	264 psi deflection temp. (DTUL) 66 psi deflection temp. (DTUL) Approximate melting temperature	204°C 216°C 225°C
Flame Class Rating	—	—	UL94V-0
Leads	Copper	—	—
Lead Finish	90/10 tin/lead solder plate	—	†
Lead Pull	—	—	8 N

*Temperature excursions to 225 °C for 2 minutes or less are permitted.

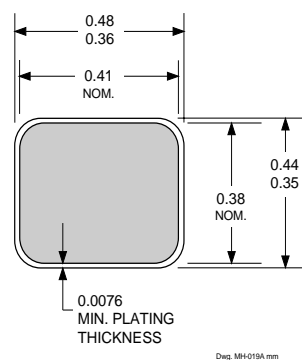
†All industry-accepted soldering techniques are permitted for these modules provided the indicated maximum temperature for each component (e.g., sensor face, plastic housing) is not exceeded. Reasonable dwell times, which do not cause melting of the plastic housing, should be used.

Sensor Location (in millimeters)

(sensor location relative to package center is the design objective)



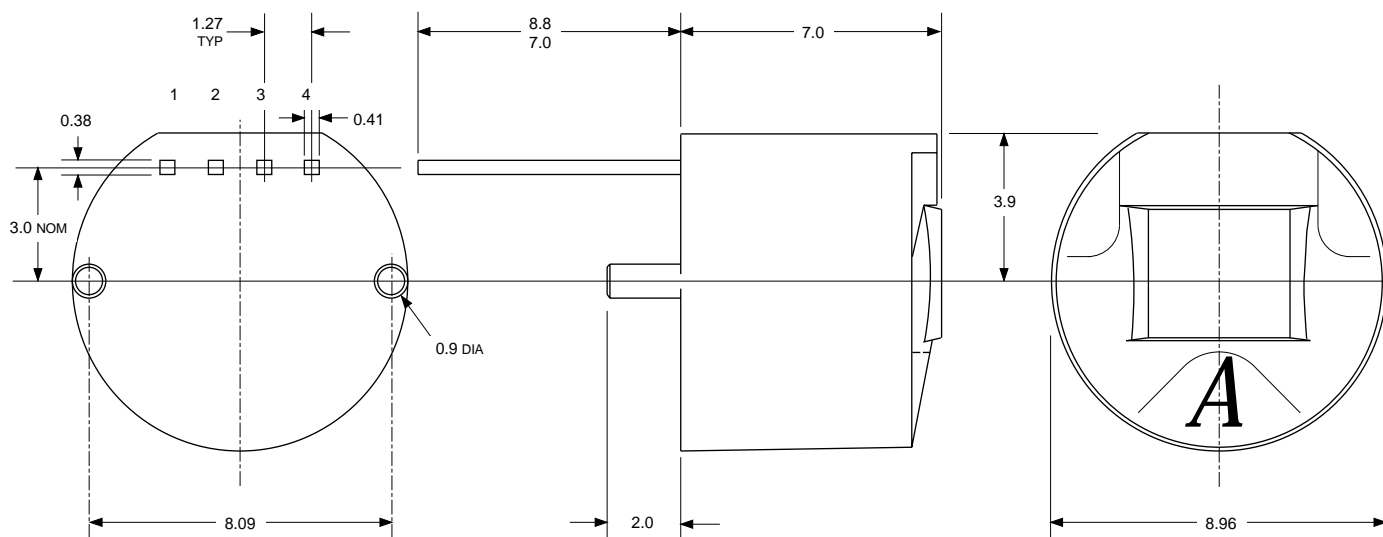
Lead Cross Section (in millimeters)



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DYNAMIC, SELF-CALIBRATING, PEAK-DETECTING, DIFFERENTIAL HALL-EFFECT GEAR-TOOTH SENSOR

DIMENSIONS IN MILLIMETERS



Dwg. MH-017-1B mm

Tolerances, unless otherwise specified: 1 place ± 0.1 mm, 2 places ± 0.05 mm.

The products described herein are manufactured under one or more of the following U.S. patents: 5,045,920; 5,264,783; 5,442,283; 5,389,889; 5,581,179; 5,517,112; 5,619,137; 5,621,319; 5,650,719; 5,686,894; 5,694,038; 5,729,130; 5,917,320; and other patents pending.

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